Dirk Hartog Island National Park Ecological Restoration Project:

Stage One – Trial hare-wallaby translocations and monitoring.

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June 2018

GOVERNMENT OF WESTERN AUSTRALIA

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The recommended reference for this publication is:
Cowen S, Rayner K, Sims C, Morris K (2018), *Dirk Hartog Island National Park Ecological Restoration Project: Stage One – Trial hare-wallaby translocations and monitoring*, Department of Biodiversity, Conservation and Attractions, Perth.

Cover photo: Kieran Wardle and Kelly Rayner releasing a rufous hare-wallaby on Dirk Hartog Island. (K. Morris / DBCA)

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Acknowledgments

We acknowledge the Malgana people as the Traditional Owners of the land known as *Gutharraguda* (Shark Bay), including the island of *Wirruwana* or Dirk Hartog Island.

The Dirk Hartog Island National Park Ecological Restoration Project fauna reconstruction team comprised: Saul Cowen, Sean Garretson, Keith Morris, Kelly Rayner and Colleen Sims. In addition, the translocation and post-release monitoring of rufous and banded hare-wallabies on Dirk Hartog Island was implemented and supported by a wide range of Department of Biodiversity, Conservation and Attractions (DBCA) staff. Other DBCA Biodiversity and Conservation Science staff involved in the project were John Angus, Mark Blythman, Mark Cowan, Judy Dunlop, Brent Johnson, Kym Ottewell, Manda Page and Juanita Renwick. We are grateful to those other staff also engaged in the Dirk Hartog Island National Park Ecological Restoration Project, including John Asher (Project Manager), Shane Heriot (Shark Bay Operations Officer), Deanne von Senger (Project Officer - Finance and Administration), and the feral cat eradication team of Dave Algar, Michael Johnston, Gary Desmond, Jason Fletcher, Neil Hamilton, Mike Onus and Cameron Tiller, whose support helped overcome some of the challenges presented by the 2017-18 field seasons. In addition, we also thank Bruce Ward for aviation and aerial tracking support, and the training he provided to aviation staff in Shark Bay.

Support was also provided by Shark Bay District staff Steve Nicholson (District Manager), Steve Mills, Kim Branch, Steve Locke, Phil Arthur, Jeff Booker, Paul and Pam Dickinson, Sharon Drabsch, Dale Fitzgerald and Robbie Jordan. DBCA employees Abby Thomas and Lei Zhang also volunteered their time to the project.

The team would also like to thank Kieran and Tory Wardle and their family for their hospitality and support of the project, as well as Lindsay, Levi and Charlie Wiltshire and Karen Sabitay. We would also like to thank Eric Roulston, Julien Wilke and Kerit Vallas at Shark Bay Aviation for their assistance with radio-tracking and island logistics.

Claudia Buters and Erin Smithies (Murdoch University) ably assisted the project during their master's placements between January and July 2018.

The implementation of the post-release monitoring program would not have been possible without considerable assistance from enthusiastic and capable volunteers, to whom we are enormously grateful for their generous donations of time and energy. This included the participation by the adventure tour company Global Gypsies who assisted with monitoring activities in October 2017.

This project was largely funded by the Gorgon Barrow Island Net Conservation Benefits Fund (www.gorgon-ncb.org.au).

Summary

The release of banded hare-wallabies (*Lagostrophus fasciatus*) and rufous hare-wallabies (*Lagorchestes hirsutus*) on Dirk Hartog Island (DHI) in August 2017, marked the first translocations of native fauna to the island as part of the Dirk Hartog Island National Park Ecological Restoration Project (DHINPERP) or “Return to 1616”.

The DHINPERP will see 12 species of mostly threatened mammal, and one species of locally extinct bird translocated to DHI in an effort to improve their conservation status and help restore ecological processes to the island. As part of this translocation program, a trial release of 12 of each hare-wallaby species, sourced from Bernier and Dorre Islands, was undertaken in August 2017 to better understand the issues associated with the capture, transport, release and monitoring of these and other species to be translocated, as well as broader challenges associated monitoring vertebrate fauna in general on DHI.

The trial translocations have been successful with all of the short-term and many of the medium-term translocation success criteria being met within the first nine months following the release. Important lessons were learned regarding the transport and care of hare-wallabies during translocations and the practicalities of fitting telemetry collars to these animals. In addition, we gained valuable insights into the post-release behaviour of these species and the difficulties of monitoring them in a relatively large landscape.

The experience and knowledge acquired in this trial has been useful in modifying protocols for the translocation of larger numbers of these species in 2018 / 19 and others in the future as well as identifying which post-release monitoring techniques are most appropriate for the DHI landscape. Recommendations are provided that should assist with future translocations.

1 Background

The vision for the ecological restoration of Dirk Hartog Island National Park (DHINP) is to create a special place with healthy vegetation and ecosystem processes that support the full suite of terrestrial native mammal species that occurred there at the time of Dirk Hartog's landing in 1616, and that this is highly valued and appreciated by the community (DEC 2012). Stage One of the DHINPERP commenced in 2011 and has resulted in the successful eradication of sheep (*Ovis aries*), feral goats (*Capra hircus*) and most likely feral cats (*Felis catus*). Stage Two will commence in July 2018 and will focus on the translocations and establishment of 12 species of mostly threatened native mammal, and one bird species. A strategic framework for this has been prepared to guide the implementation of this stage of the project (Morris *et al.* 2017).

Of the 12 species of mammal to be translocated to DHI, ten species are known to have previously occurred on the island. However, there are no confirmed sub-fossil or historic records that indicate that the banded hare-wallaby or rufous hare-wallaby occurred on DHI, despite them occurring on nearby Bernier and Dorre Islands, and on the nearby mainland. However, given the restricted distribution of these two threatened species, they were included in the suite of mammals to be translocated to improve their conservation outlook. Prior to the translocation of 50-100 of each of these species to DHI in 2018/19, it was considered prudent to undertake a trial translocation in 2017 using smaller numbers of founders to evaluate the feasibility and logistics of translocating these two species to Dirk Hartog Island. This report provides the results of these translocations and recommendations about future translocations of these and other species.

1.1 Site description

Dirk Hartog Island is located in the Shire of Shark Bay in Western Australia at approximately -26° S and 113° E and forms part of the Shark Bay UNESCO World Heritage Area. It falls within the DBCA Parks and Wildlife Service's Shark Bay District, which in turn forms part of the Midwest Region. The island is approximately 80km long and up to 12km wide with a total area of 62,000 ha, making it the largest island in Western Australia (Figure 1). The island contains a range of different terrestrial habitats, including *Acacia*-dominated shrubland communities, *Triodia*-dominated grasslands, *Thryptomene dampieri* heath, consolidated and mobile dune-systems with large areas of *Spinifex longifolius* and many small birrida clay-pans vegetated by chenopods (Beard 1976).

The island was a pastoral lease from the 1860s to 2009, when most of it became a National Park. Some existing and additional small areas of freehold were granted to the former lessee at this time. Maritime lighthouse facilities and areas for the purpose of recreation are also under leasehold at the north end of the island and additional areas have been classified as heritage reserves. Following 150 years of grazing by sheep and feral goats, the island's vegetation had been heavily impacted by grazing and become degraded in many parts. Since destocking commenced in 2007, vegetation cover is estimated to have increased by more than 50% in some parts of the island (van Dongen and Huntley 2017). All sheep and feral goats have now been removed from DHI (Asher and Heriot 2018), and it is likely that feral cats have been eradicated from the island.

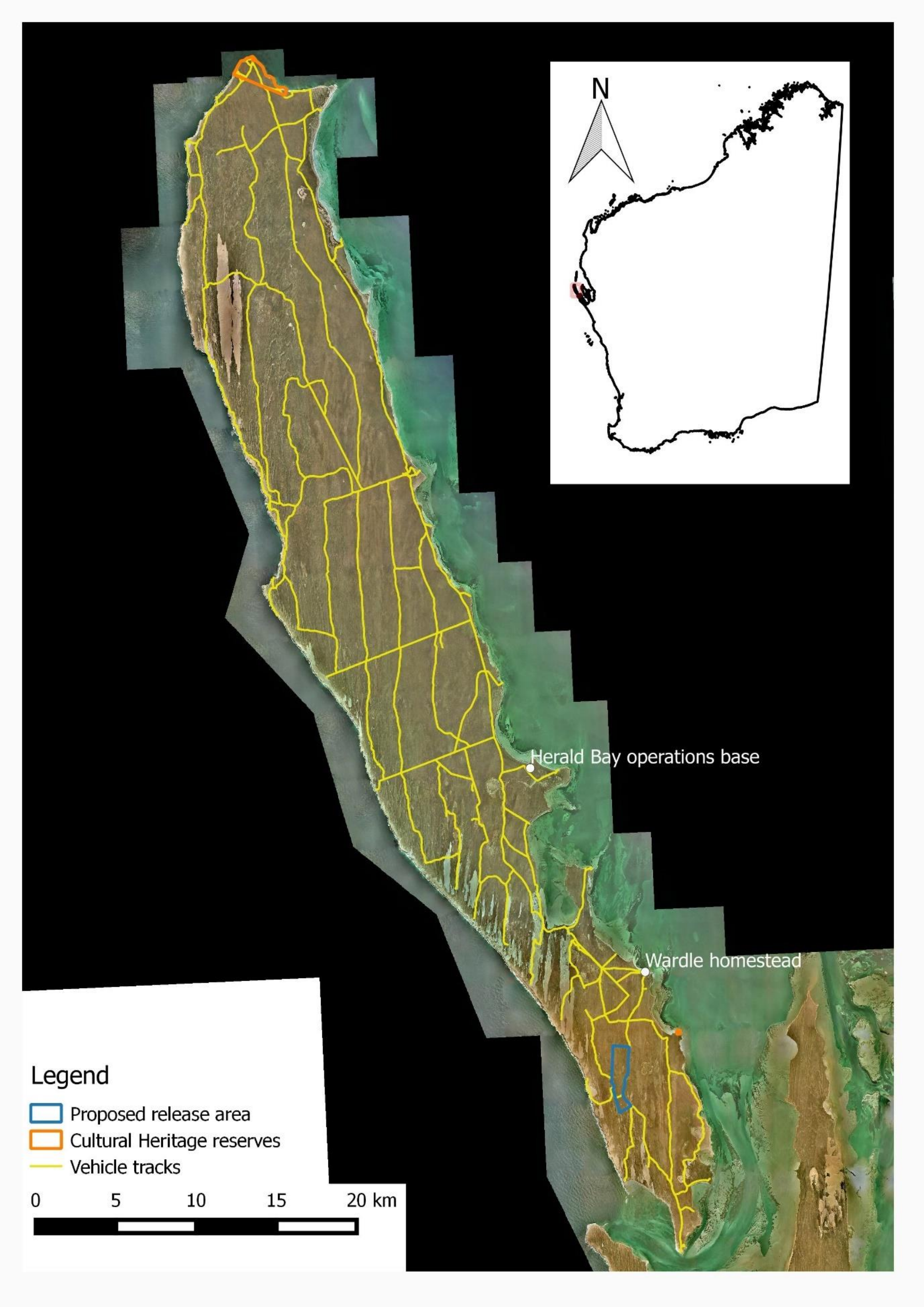

Figure 1. Map of Dirk Hartog Island, indicating important areas and 4WD and ATV track network.

1.2 Species descriptions

1.2.1 Banded hare-wallaby

The banded hare-wallaby (*Lagostrophus fasciatus*) is a small, terrestrial, macropodid marsupial and is the sole-remaining member of a now extinct lineage of ancient kangaroos (Lagostrophinae), unrelated from other hare-wallaby species (Llamas *et al*. 2015). Previously widespread across southern Western Australia, wild populations of banded hare-wallabies are restricted to Bernier and Dorre Islands in Shark Bay. These locations are small (~5,000ha each), isolated and vulnerable to large variations in environmental conditions, especially rainfall. Estimates of the total population for these two islands varies from 2,000 to 9,700 with recent estimates of around 5,000 individuals (Sims and Cowen, 2018). Additional populations have been established on Faure Island in Shark Bay and Wadderin Sanctuary near Narembeen, and a translocation program is underway at Mt Gibson Sanctuary near Wubin. Banded hare-wallabies have been introduced to Dirk Hartog Island once before, with 21 animals released between 1974 and 1978. Failure of this translocation was largely attributed to predation by feral cats, compounded by inadequate vegetation cover caused by grazing and drought (Fisheries and Fauna 1979).

The banded hare-wallaby is a nocturnal species, with bimodal peaks of activity in the first and last three hours after sunset/before sunrise. Habitat preferences on Bernier and Dorre Islands are for shrubland communities, characterised by dense *Acacia* thickets. These thickets provide shelter during the day and cover from predators if disturbed (Short and Turner 1992; Short *et al*. 1997). While not strictly a fossorial species, the banded hare-wallaby is known to dig shallow scrapes under cover to rest in during the day (Hardman and Moro 2006).

Predominantly a browser (Short and Turner 1992), the banded hare-wallaby has a broad and varied diet, feeding on a range of grasses, shrubs and other dicotyledonous plants (Richards *et al*. 2001). Observations in captivity suggest a preference for several *Acacia* species (*A. ligulata*, *A. ramulosa*, *A. sclerosperma*, *A. tetragonophylla*) (Richards 2012).

The lifespan of the banded hare-wallaby is thought to be up to six years in the wild and while capable of reproduction in their first year, it is assumed that most do not breed until their second. Breeding may occur year-round, although on Bernier and Dorre, the occurrence of pouch-young/lactation generally peaks in autumn (Richards *et al*. 2001). Young occupy the pouch for around six months and are weaned at nine (Prince and Richards 2008). Females are monovular (Tyndale-Biscoe 1965) and usually produce one offspring per year, although two offspring may be raised if environmental conditions are particularly propitious (Richards *et al*. 2001).

The sex-ratio in banded hare-wallabies appears to be biased in favour of females (Richards *et al*. 2001) and male territories will overlap with several females (Prince and Richards 2008). Males and females appear to live within well-defined home ranges (Richards *et al*. 2001; Prince and Richards 2008) and interactions between adult males are often aggressive, in contrast to other interactions involving females. Average home range size is estimated to be around 11ha, (Hardman 2006) although this was calculated using data from recently translocated individuals on Peron Peninsula and may not be representative of well-established populations.

Threats to the banded hare-wallaby are chiefly from introduced predators, particularly the red fox (*Vulpes vulpes*) and feral cat. As such, reintroductions of this species are restricted to areas free of cats and foxes as it is unlikely hare-wallabies will persist in locations where even low densities of these predators are present. The evidence for banded hare-wallabies having occurred previously on Dirk Hartog Island is largely circumstantial but compelling. Baynes (1990) found no evidence of banded hare-wallabies in subfossil deposits and as such, the translocation of this species to Dirk Hartog Island is being treated as a conservation introduction rather than a reintroduction. However, anecdotal evidence from the explorers Dampier (1699) and Peron (1803) suggests that this species may have occurred on the island (Rayner *et al*. 2018) and subfossil remains have also been recovered from the adjacent mainland at Edel Land and Peron Peninsula.

The banded hare-wallaby is listed as Vulnerable under IUCN and EPBC Act (1999) criteria and in Western Australia under Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice (2017).

1.2.2 Rufous hare-wallaby

Like the banded, the rufous hare-wallaby (*Lagorchestes hirsutus*) is also a small macropodid and is similar in size, shape and much of its behaviours. However, it is only distantly related to the banded hare-wallaby and is more closely related to modern kangaroos (Macropodinae) (Llamas *et al*. 2015). As with many other native marsupials, rufous hare-wallabies were formerly far more widespread than they presently are and used to occur over much of western and central Australia. Currently, extant wild populations occur only on Bernier and Dorre Islands (subspecies *L. h. bernieri*) Additionally, a translocated population derived from a former Tanami Desert population (*L. h.* sp. 'mala') occurs on Trimouille Island in the Montebello Islands in north-western Western Australia. Other populations of this subspecies exist inside enclosures in Western Australia, the Northern Territory and New South Wales. A third subspecies that formerly occurred in south-western Australia (*L. h. hirsutus*) is listed as extinct.

The rufous hare-wallaby is nocturnal and generally solitary (Short and Turner 1992) with relatively small home ranges compared to those of the banded hare-wallaby (about seven hectares although this is based on data from recently translocated individuals (Hardman 2006)). In this scenario, home ranges may overlap in relation to food availability. Habitat preferences also differ between these hare-wallaby species, with rufous preferring more open areas of *Triodia* grassland communities with scattered low dense shrubs but often also encountered in dune systems including along coastlines. They will shelter under low shrubs or *Triodia* hummocks, digging small scrapes under vegetation (Johnson and Burbidge 2008). Unlike the banded, the rufous hare-wallaby is a grazer and will feed on *Triodia* spinifex (e.g. *Triodia plurinervata*) but also on more nutritious forbs and grasses (Johnson and Burbidge 2008).

Longevity in rufous hare-wallabies has been difficult to assess (Richards *et al*. 2001) in the wild but it's reasonable to assume that it would be similar to banded hare-wallabies given their comparable life-history traits. Like banded hare-wallabies, rufous hare-wallabies are polyoestrus, monovular (although twinning has been reported on one occasion) and can breed year-round (Lundie-Jenkins 1993; Richards *et al*. 2001). Female 'mala' are known to reproduce at 5-18 months with males reaching sexual maturity at 14 months. Pouch life is around five months and hence females are capable of producing up to two offspring in a year, with no apparent peak breeding season. Sex ratios in this species are usually close to parity (Richards *et al*. 2001).

As for the banded hare-wallaby (and many other critical weight-range mammals), the main threat to rufous hare-wallabies is predation by introduced predators. However, some native predators, such as the wedge-tailed eagle (*Aquila audax*) will also prey on this species (Short *et al*. 1992; Richards and Short 1998). As with the banded hare-wallaby, Baynes (1990) found no evidence of subfossil remains of rufous hare-wallabies on DHI and no anecdotal evidence exists either. However, given the proximity of extant populations on Bernier and Dorre Islands and the historical presence on the adjacent mainland, it seems possible that rufous hare-wallabies did occur on Dirk Hartog Island prior to the introduction of invasive species such as feral cats. Nevertheless, for the purposes of this project, the translocations of both hare-wallabies will be treated as conservation introductions.

The rufous hare-wallaby is listed as Vulnerable under IUCN criteria, as is *L. h. bernieri* under the EPBC Act (1999) and Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice (2017). *L. h.* spp. is listed as Endangered under EPBC Act (1999) and Schedule 2 of the Wildlife Conservation (Specially Protected Fauna) Notice (2017).

1.3 Timeline

The trial translocations commenced on 2 August 2017 with the pre-capture monitoring of the Dorre Island populations of hare-wallabies, followed by the monitoring of Bernier Island populations on 18 August. Once the populations on Bernier and Dorre Islands had been assessed as being sufficiently abundant (>2000 for banded; >1000 for rufous) for the removal of founders of each species (Sims and Cowen, 2018), 12 (four male, eight female) banded hare-wallabies and 12 (four male, eight female) rufous hare-wallabies were captured, processed, transported and released on DHI on 29 and 30 August 2017 respectively. This was followed by a three-month period of intensive ground and aerial monitoring, and then less intensive aerial monitoring for four months. Radio-collars were removed in May 2018. Figure 2 below indicates the timings of the translocations and monitoring of hare-wallabies.

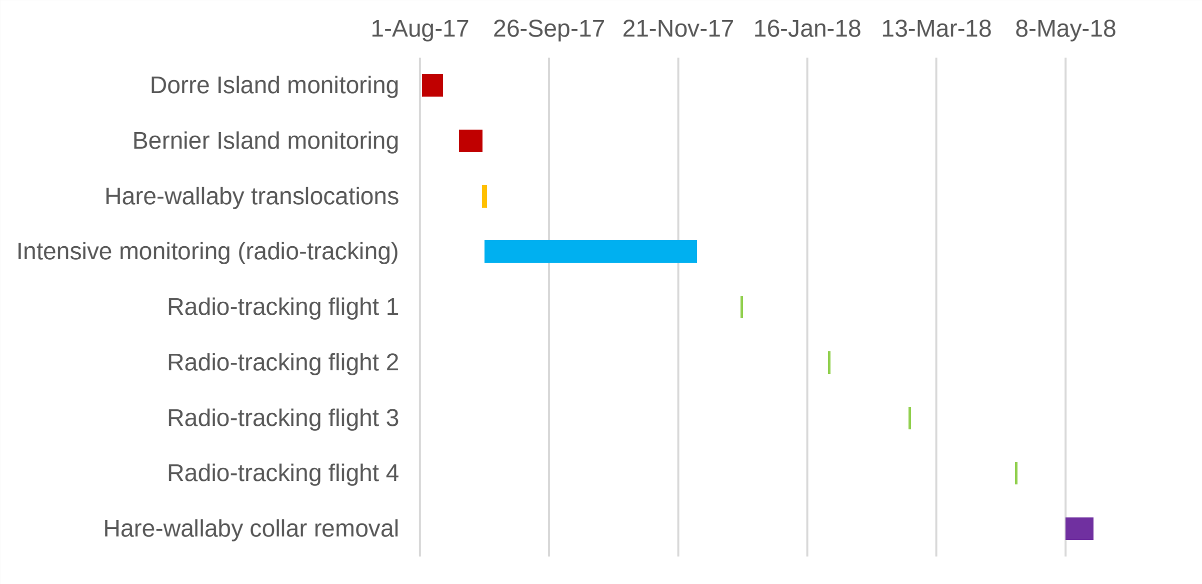

Figure 2. *Gantt chart showing timeline of outcomes from translocation between August 2017 and May 2018.*

1.4 Climate and weather

Dirk Hartog Island has a semi-arid climate, characterised by winter rainfall and dry summers with a mean annual rainfall of approximately 230mm. Occasional heavy falls of rain may occur in summer and autumn, particularly when associated with cyclones moving down the west coast of Western Australia. Figure 3 shows the weather conditions that occurred on Dirk Hartog Island during the six months prior to and following the translocation and indicates that while September was the wettest month for the period, very little rain fell from October onwards.

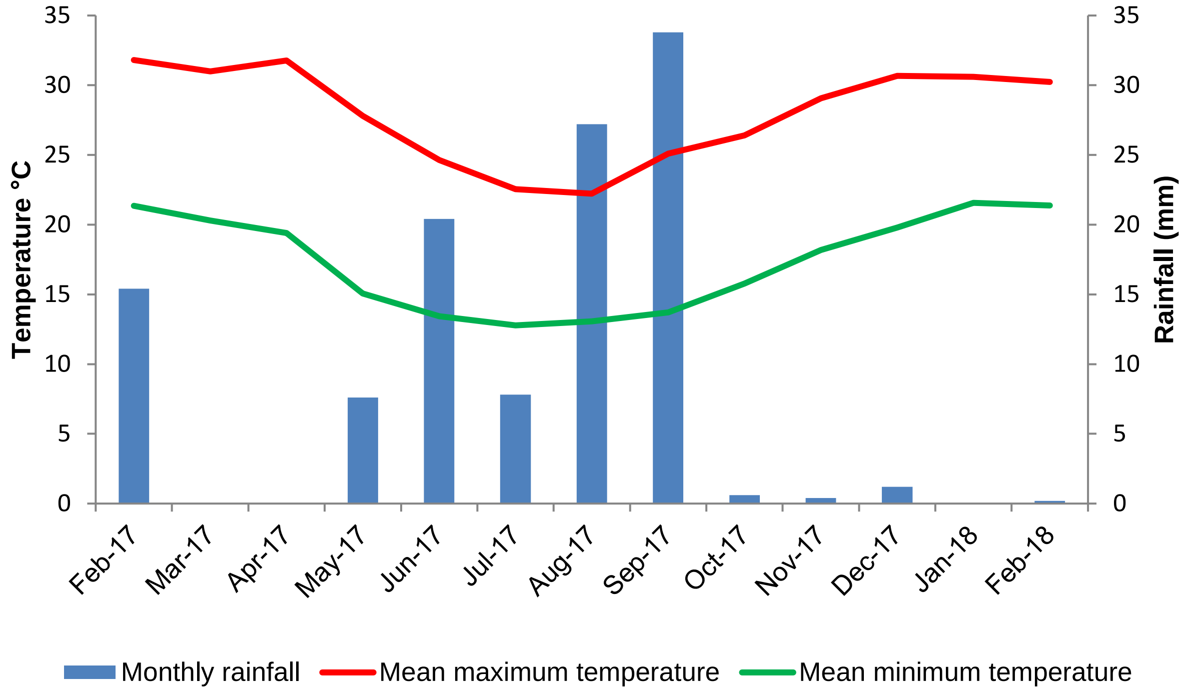

Figure 3. Total monthly rainfall (bar graph) and mean monthly temperatures (line graphs) for Dirk Hartog Island from February 2017 to February 2018.

The timing of the trial translocation of hare-wallabies was set as late winter/early spring as this was when calm sea conditions were most likely, an important safety consideration for vessel-based capture teams on Bernier and Dorre Island as well as an important welfare consideration for the animals being transferred to Dirk Hartog Island.

2 Methods

2.1 Translocation Proposals

Translocation Proposals and Animal Ethics applications were prepared in May 2017 and approved in August 2017 (AEC 2017/17).

Success criteria listed under the translocation proposals for the species were as follows:

Short-term (0 - 9 months)

1. at least 50% of the radio-collared, released hare-wallabies survive for the first four months after release.
2. any causes of mortality understood and ameliorated.
3. founders have maintained or increased bodyweight, condition maintained.
4. some evidence of successful recruitment of those that may have been larger pouch-young when translocated.

(Meeting these short-term success criteria for the trial translocation (2017) will be a trigger for proceeding with the full translocations (2018, 2019))

Medium-term (10 - 36 months)

1. population has established and expanded habitat is used.
2. body weight and condition is maintained.
3. further evidence of successful reproduction; presence of pouch-young, or F1 generation (from females with large pouch-young when translocated).
4. hare-wallabies are recorded during spotlight and/or trapping monitoring sessions.

2.2 Translocation site selection

Using ecological knowledge of the hare-wallabies on Bernier and Dorre Island, translocation sites on DHI were selected based on habitat suitability and condition. The most appropriate site for establishing facilities from which staff could operate was then selected. Habitat suitability involved an assessment of the vegetation for food and refuge for both species of hare-wallabies. Banded hare-wallabies are generalist browsers and require dense shrubs for shelter, while rufous hare-wallabies are grazers and shelter under *Triodia* hummocks. The condition of the habitat was also an important consideration, given that the island’s vegetation communities are recovering from grazing pressure from the >7000 goats and sheep that were removed between 2009 and 2017. Remote-sensing technology has been used to monitor the recovery of vegetation on Dirk Hartog Island since the destocking of ungulates commenced (van Dongen and Huntley 2017) and these data were used to select locations of shrublands and hummock grasslands where vegetation recovery had been highest.

Using this information, a release area was designated in the south of DHI (Figure 1, Figure 4) approximately 10 km south of the Dirk Hartog Island Eco-lodge, which became the base for the post-release monitoring team during spring 2017. Four sites within or in proximity to this area (Figure 4) were selected based on habitat suitability, with two sites in *Triodia*-dominated communities (preferred by rufous hare-wallabies) (Figure 5) and two in *Acacia*-dominated communities (banded hare-wallabies) (Figure 6).

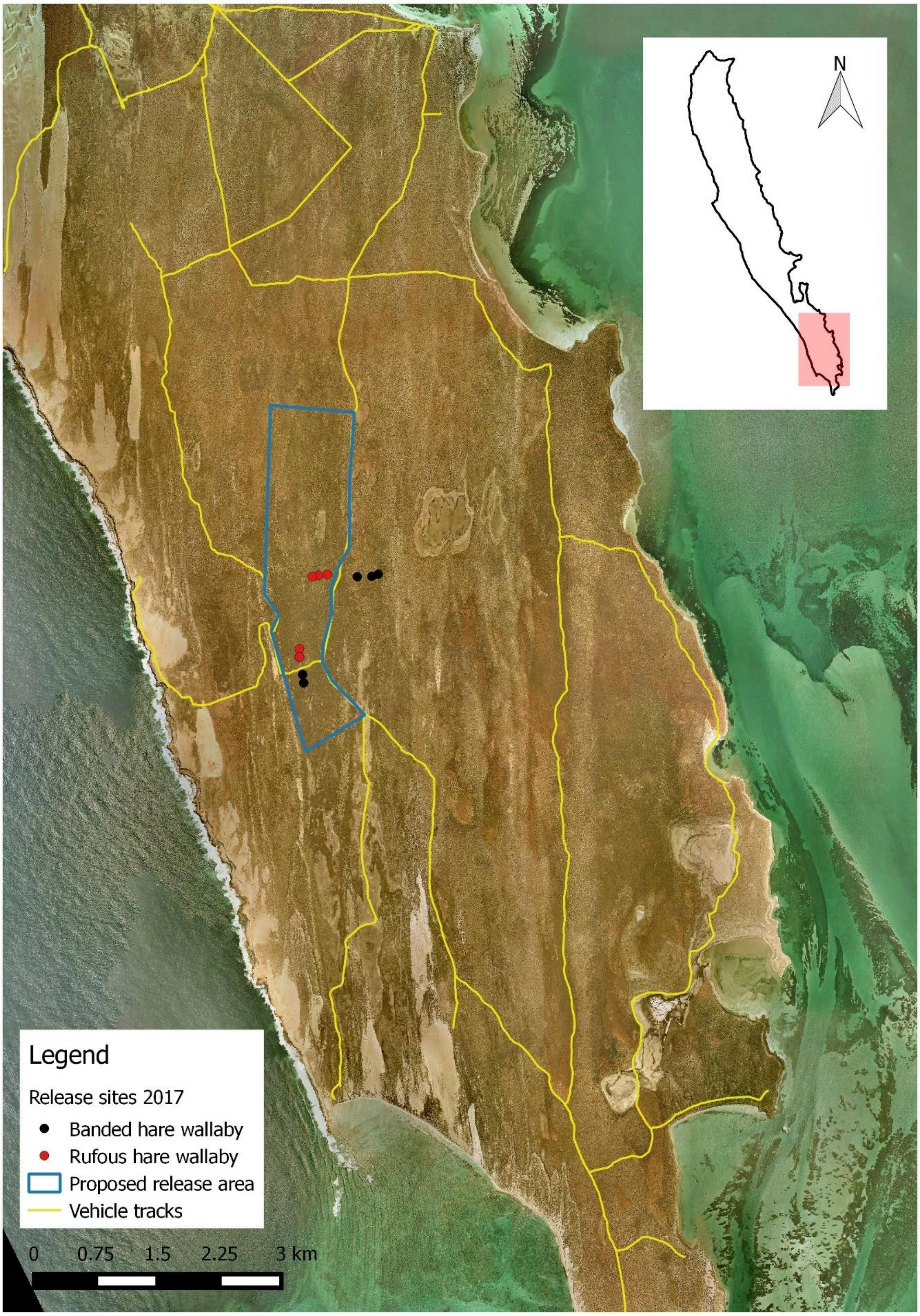

Figure 4. Map of southern end of Dirk Hartog Island indicating proposed release area and actual release sites of banded and rufous hare-wallabies.

Figure 5. Example of Triodia-dominated community nominated as release location for rufous hare-wallabies (© S. Cowen/DBCA).

Figure 6. Example of Acacia-dominated community nominated as release location for banded hare-wallabies (© S. Cowen/DBCA)

2.3 Capture, transport and release

2.3.1 Capture of hare-wallabies on Bernier and Dorre Islands

Capture of founder hare-wallabies on Bernier and Dorre Islands used a standard operating procedure (SOP 9.6), employing the use of spotlights and hand-nets (Department of Biodiversity, Conservation and Attractions 2017). Techniques using live-capture traps are not appropriate for hare-wallabies as they are not readily trapped (Richards *et al*. 2001) and are prone to the potential fatal disorder known as 'capture' or 'stress' myopathy, which can be induced by stressors such as trapping and handling (Paterson 2007). Macropodids can be particularly susceptible to capture myopathy (Green-Barber *et al*. 2018) with rufous hare-wallabies known to be particularly vulnerable (Cole *et al*. 1993). Hand-netting required a team of five to six, with one member to locate hare-wallabies in the beam of a 35W spotlight, one to carry necessary field-processing equipment and three to four more others with hand-nets to catch the animal. Chases were minimised to <100m to mitigate risk of capture myopathy (Paterson 2007).

Once animals were captured they were immediately assessed for suitability for translocation, taking into account sex, age, condition and breeding status (i.e.

presence and size of pouch-young or young-at-foot). Captured animals had morphometric measurements taken (including capture weights) and had Passive Integrated Transponders (PIT, Allflex ™ FDX-B Microchip, ca.11 x 3mm) inserted at the rear of the neck. To mitigate the risk of capture myopathy, individuals selected for translocation were treated with selenium/vitamin E (0.2ml/kg), Diazepam (0.5mg/kg) and Azaperone (2mg/kg). Selenium and Vitamin E are thought to play a role in reducing the likelihood of capture myopathy, particularly if the animal is likely to be subject to further stress. Sedation through Diazepam and Azaperone are used to maintain the animal in a calm state during transport and handling. While sedation with Diazepam only lasts a few hours, Azaperone sedation may last up to eight hours. However, the effect of Azaperone sedation is more predictable if Diazepam is administered prior. In this translocation, only rufous hare-wallabies were sedated during transport and handling, given their higher risk of capture myopathy. Handling was kept to minimum under all circumstances, since this is another stressor that may potentially exacerbate the risk of capture myopathy (Paterson 2007).

2.3.2 Transfer and holding procedure

After capture, hare-wallabies selected for translocation were held in a black cotton bag inside a pet-pack (PP30 62 x 43 x 45 cm) and then transferred off either Bernier or Dorre Islands by tender to a charter vessel for the journey to Dirk Hartog Island (four to five hours) overnight. Whilst every attempt was made to stow animals in a cool, quiet environment to minimise stress, it was impossible to eliminate all noise and hence the sedation methods used in 2.2.1 were vital in minimising the animals' stress levels during transport.

On arrival at Dirk Hartog Island, all animals were reweighed, small punches of ear-tissue taken for subsequent DNA extraction and analysis, and radio-telemetry collars fitted to all hare-wallabies for post-release monitoring. Eighteen hare-wallabies (nine rufous; nine banded) were fitted with VHF radio collars (VHF Core (custom-built), Sirtrack, Havelock North, NZ) with a four hour mortality sensor. In addition, six animals were fitted with telemetry collars with GPS capabilities (FLV-R, Telemetry Solutions, Concord, CA, USA). Ensuring snug collar-fit was crucial, as significant loss of weight, resulting in loosening of the collar and subsequent entrapment of forelimbs is also a known risk of mortality for hare-wallabies (Hardman *et al*. 2016). Most animals were calm during processing and collaring but those that were agitated were administered with Diazepam (0.5mg/kg) to minimise stress and to facilitate optimal fitting of collars. Once animals had been fully processed, they were again held in a cool, quiet area in clean black cotton bags until after dark.

2.3.3 Release procedure

Animals were taken in pet-packs by vehicle and released after dark at designated release sites, as outlined in section 2.1. Immediately prior to release, hare-wallabies were checked again for collar-fit and to ensure fore-limbs were not caught in collars. Animals were observed at time of release to ensure they had not sustained any injuries during translocation. Once this was confirmed, staff and volunteers departed the area quickly and quietly to minimise additional disturbance to the animals.

2.4 Post-release monitoring

2.4.1 Ground radio-tracking

The primary method of post-release monitoring of hare-wallabies was regular ground tracking of radio-telemetry collars (radio-tracking). Radio-tracking allowed the location and status of radio-collared animals to be monitored remotely and data on behaviour, movement and survivorship to be obtained (Millspaugh and Marzluff 2001). Previous radio-tracking of translocated hare-wallabies has shown that some individuals show tendencies to remain in small areas (‘residents’), whereas others are more mobile (Hardman *et al*. 2016). Therefore, we anticipated that translocated hare-wallabies would vary considerably in their nightly movements and some animals may move considerable distances. Radio-tracking protocol for this translocation was to ensure that hare-wallabies were not to be approached closely during the day to avoid flushing animals from vegetation cover, which would potentially expose them to predation by raptors, a known risk with translocations of these species (Hardman *et al*. 2016).

More accurate locations of radio-tracked animals were obtained through triangulating VHF signals by obtaining compass bearings for the strongest signal from three or more locations. Field-staff aimed to record regular locations using this method, particularly for animals that were highly mobile. Triangulation data were plotted spatially using the Triangulation plugin (Animove, https://www.faunalia.eu) in Quantum GIS (version 2.18.16 Las Palmas)

The six GPS collars were pre-programmed on a schedule to record locations at regular intervals over time. Several duty schedules were trialled for this translocation to design an optimal number of GPS fixes per day to investigate spatial and temporal variation in movement and activity. These schedules are shown in

Table 1. GPS fixes were screened for accuracy and poor-quality fixes were removed based on a) no fix at all b) HDOP (horizontal dilution of precision, i.e. proximity of satellites to each other when fixes are acquired) >5.0 (as in Moen *et al.* 1997) and c) 2D fixes vs. 3D fixes. Any fixes that met any of these criteria were deleted from the dataset prior to analysis. GPS data were used to generate 95% Minimum Convex Polygons (MCP95) and Kernel Density Estimates (KDE95) using Animove in Quantum GIS, which provide an approximation of utilisation distribution.

Table 1. Fix schedules used to program GPS telemetry collars deployed on hare-wallabies in August 2017

Program	No. fixes per day	Fix time (secs)	Period(s) (interval)	No. days
A	8	90	1840-0600 (~120 mins)	12
B	8	90	1900-0500 (~120 mins)	14
C	8	90	1830-0530 (120 mins)	16
D	11	90	2200-0230 (30 mins)	4
E	21	90	1930-0500 (30mins)	6
F	13	90	1900-2130 0300-0530 (30 mins)	1
G	1	90	Midday	39
H	9	90	1930-2100 0330-0500 (30 mins)	11
I	3	90	2100-2300 (60 mins)	1

In addition to monitoring the movements of translocated hare-wallabies, the mortality function of the radio-collars allowed monitoring of post-translocation survivorship. Any translocation of animals to new environment entail a range of risks and hazards including higher risk of mortality (Chipman *et al*. 2008) and low survival rates can impact the long-term chance of success (Armstrong and Seddon 2008). Understanding the causes of any mortalities in this trial was crucial to mitigating these risks in future, large-scale translocations. As such, locating and retrieving the carcass of any dead hare-wallaby within a short timeframe was extremely important, so that a comprehensive post-mortem could be carried out. Establishing if capture myopathy was implicated in the cause of death required adherence to appropriate collection and storage of organs for histopathology analyses. In the case of predation events, swabs of wound sites can be used for DNA analysis to establish the predator(s) involved. To this end, radio-tracking was carried out daily from the first day after release for more than 12 weeks post-release (Figure 2). Personnel aimed to locate a radio signal from each animal every day to establish if the collar was in 'live' or 'mortality' mode (as indicated by a modified signal pulse rate). If a collar was detected in mortality mode, staff were to radio-track to the collar's location and retrieve either the slipped collar or the carcass as quickly as possible.

2.4.2 Aerial radio-tracking

To monitor survivorship after the initial 12-week intensive-monitoring period (Figure 2), radio-tracking of animals wearing collars was continued at six-week intervals over summer and early autumn. Detection and location of radio-telemetry collars on the ground can be potentially time-consuming as signals can be interrupted by vegetation and topography. A more efficient method of obtaining radio signals and establishing locations is through the use of aircraft. We chartered a Cessna 172 fixed-wing light aircraft (Shark Bay Aviation) and fitted telemetry antennas underneath both wings (CASA engineering order number EO TDE5788-01-R1). After initially checking for 'live' vs. 'mortality' pulse rates, collar locations were obtained through flicking between right and left antennas until the signal reaches a null (as outlined in Seddon and Maloney 2004) and then a location was recorded using a GPS unit.

2.4.3 Remote cameras

Establishing a protocol for long-term monitoring of both species of hare-wallabies was a priority for this trial translocation, since neither species has a propensity to enter live-capture traps. Remote cameras present a potentially valuable monitoring tool for species that are difficult to trap and may be relatively economical compared to other techniques such as conducting spotlighting or scat/track surveys. As such, a trial remote camera survey was conducted after the intensive monitoring by radio-telemetry. Remote camera data has been used to model estimates of occupancy of animals in a given location with some accuracy but in order to estimate occupancy, values for detection probability for given species must be obtained first (MacKenzie *et al*. 2006). In order to produce an estimate of detection probability, 30 un-lured, remote cameras (Hyperfire PC900, Reconyx, Holmen, WI, USA) were deployed between 10 - 19 November 2017 and retrieved on 14 - 15 May 2018 (a total of 5472 camera trap-nights). These were deployed on a six by five grid with 500m spacing between cameras, covering approximately 500 ha with all sites at least 50m away from tracks to avoid theft or any bias caused by their proximity. Camera images were downloaded, databased and prepared for additional analysis in CPW Photo Warehouse (Colorado Parks and Wildlife). Estimates for detection probability (Ψ) and occupancy were then calculated.

In the event of a hare-wallaby having its collar removed due to injury prior to the end of the intensive monitoring period, up to six remote cameras were deployed in a grid in the vicinity of its last known location. This was a relatively poor method of monitoring these individuals, as this provided no information on survivorship or behaviour unless the animal was captured by the camera. However, it was preferable to do this rather than abandoning any monitoring of these individuals, particularly if they had pouch-young.

During the trial translocation, the cat eradication team continued to monitor the entire island for feral cats that may have evaded any of their control methods that had been implemented. This included 61 remote cameras that were deployed and run continuously south of a cat-proof fence that had been constructed separating the southern third of the island from the northern two thirds. Cameras were spaced at one to two-kilometre intervals in a grid but almost all were along either formed or quad-bike tracks and were serviced on a quarterly basis. Time and date-stamped images were provided to the hare-wallaby monitoring team (M. Johnston, DBCA). Due to the large number of cameras deployed across the landscape, these provided a useful additional tool to monitor movements that otherwise would not be picked up through radio-tracking.

2.4.4 Tracks and scats

At the time of the hare-wallaby translocations, no other macropodids or potoroids occurred on Dirk Hartog Island, so any tracks of medium-sized hopping mammals were indicators of the presence of either species of hare-wallaby. These represented a useful method of monitoring the movement and behaviour of animals. However, given the small numbers of animals released in this trial, field-staff only recorded tracks on an ad-hoc basis when they were encountered in new areas. Track observations were extremely valuable in locating individuals who could not be detected using other monitoring techniques.

The collection of scats from animals can be useful for a number of purposes, including extraction and analysis of DNA and diet studies. Scats were collected from each individual hare-wallaby on arrival at Dirk Hartog Island. These were stored in 30mL specimen containers on silica gel beads with a ball of cotton wool to minimise movement and breakage. For the purposes of the trial, we wanted to better understand how dietary preferences might vary between source populations and Dirk Hartog Island and some of these samples have formed part of a preliminary analysis to this end. Any seeds found in these samples will also form part of a germination study to investigate endozoochory (seed dispersal) by hare-wallabies.

2.4.5 Recapture for radio-collar checking and/or removal

Towards the end of the intensive monitoring period (early to mid-November 2017), attempts were made to recapture all radio-collared hare-wallabies to assess the collar, conduct health-checks and check for any signs of reproductive activity. Animals with GPS collars either had the collars removed or replaced with VHF only collars as this was when the battery life of the GPS collars was expected to expire. Due to the inherent risks associated with the capture of hare-wallabies (including injury to animals or staff, ejection of pouch-young and capture myopathy), the recapture of translocated animals before this period was only done when welfare concerns for animals made it imperative that the animal have its collar checked or removed.

In addition, a second period of hare-wallaby recaptures for the purpose of collar removal took place over two weeks in May 2018, just prior to the VHF-only collar batteries expiring. This permitted the maximum period for monitoring (especially for survivorship) using these collars. It also provided a second opportunity to assess health and recruitment as well.

Heath-checks included checking for presence and abundance of ectoparasites and signs of any injuries. An overall condition score was assessed using two methods. A quantitative condition index was calculated dividing the cube root of weight (g) by long pes length (cm) (as per Caughley *et al.*, 1988) and a qualitative estimate using a scale of one to five using the following criteria (from Chapman *et al.*, 2015):

1 - Emaciated (very little muscle mass to touch, transverse processes of spine prominent)

2 - Under weight (little flesh, able to feel transverse process of spine easily)

3 - Ideal (able to (just) feel transverse processes and able to feel a 'good' amount of flesh between spinous processes)

4 - Over-weight (only just able to feel spinous processes, unable to feel transverse processes)

5 - Obese (unable to feel spinous processes, can see rolls of fat around neck and on tail)

The technique for recapture was similar to the method used to capture the founder animals on Bernier and Dorre Islands. Animals were located during the day using the VHF-collar signal and then again at night for the capture attempt itself. A combination of spotlighting and hand-netting was used but pursuits were limited to <100m to minimise stress and risk of injury and no captures were attempted in wet conditions. Once captured, morphometric measurements were taken, collar-fit and body condition assessed and pouches checked for signs of reproductive activity. Collars were removed if there were any signs of significant injury (e.g. open or scabbed wounds). If the collar fit was suboptimal or there were signs of fur loss or reddening of the skin, they were adjusted. All collars on animals caught in May 2018 were removed.

As an ancillary method to spotlighting/hand-netting, Thomas traps were used to target individual animals that were in locations where they were difficult to catch in nets. Hare-wallabies are not easily caught in live-capture traps (Richards *et al*. 2001) so traps were wired open initially to maximise the likelihood of an animal entering the trap. Bait included apple, carrot, sweet potato, cucumber, molasses, rabbit-muesli and Dairy-Krave® (Feed Flavors Inc., Wheeling, Illinois, USA).

In May 2018, a 'drift-fence' was employed along with hand-netting to reduce pursuits of animals with hand-nets. Target animals were tracked to their daytime refuge and prior to sunset a field-team would assemble a drift-fence to semi-encircle 150 to° 270° around the refuge. The fence was made from aviary mesh and dropper-posts (Figure 7) with metal turf-pegs to hold the base down. The team would then slowly approach the refuge to flush the hare-wallaby towards and into the fence which would impede its flight long enough to be captured either by hand or hand-net. This greatly reduced the pursuit time and increased the likelihood of a successful capture.

Figure 7. 'Drift-fence' set up, showing aviary mesh and metal droppers semi-encircling a hare-wallaby refuge (© K. Grosser/DBCA).

2.4.6 Post-mortem of deceased hare-wallabies

In the case of any mortalities during the intensive post-release monitoring period, it was important that a post-mortem could be carried out as soon as possible to establish the probable cause of death, especially if capture myopathy was suspected. Once the animal was located (by tracking the mortality signal from its telemetry collar), the animal was photographed *in situ* and the site inspected for possible causes of death, for example, signs of a predator. The carcass was then collected, and the post-mortem commenced within an hour of collection. Initially an external examination was completed beginning with an inspection for wounds or abrasions then an assessment of overall body condition, level of decomposition, time since death (rigor mortis), ecto-parasite load (specimens collected), dental condition and the fit of the collar. The animal was then dissected and examined internally. An assessment was made of size and colour of organs, the contents of the digestive tract were collected as were tissue samples from the heart, lungs, kidneys, liver, spleen and gall bladder. Additionally, the skin of the neck was dissected and an internal examination of the area conducted to check for signs of bruising. All internal samples were stored in formalin (10%) and submitted to Murdoch University for examination. The carcass was retained and frozen in case further samples were required.

3 Results

3.1 Capture and translocation of hare-wallabies

A total of 26 hare-wallabies (13 banded; 13 rufous) were captured on Bernier and Dorre Islands, on the 28 and 29 August 2017 respectively. Of these, 12 of each species (six from each island) were selected for translocation (Appendix 1) with a sex ratio of 2F:1M. None of the females selected for translocation had pouch-young or young-at-foot.

The vessel transporting the hare-wallabies departed the islands at approximately midnight, arriving at Homestead Bay on Dirk Hartog Island at approximately 0500 hours. Animals were transported ashore, processed and collars fitted during the day and released in the early evening, at about 2000 hours (Figure 8). While most animals were calm during processing and collaring, six rufous and four banded hare-wallabies were considered agitated enough to require sedation before collaring. Two rufous hare-wallabies exhibited hypersalivation, indicating stress in response to being held and handled.

On release, some rufous hare-wallabies appeared somewhat disorientated, probably as a result of the earlier sedation. However, most banded hare-wallabies appeared calm and moved away, often feeding immediately on vegetation.

Figure 8. Left - release of a rufous hare-wallaby and Right - the release of two banded hare-wallabies (© K.Morris/DBCA and Richard Manning).

3.2 Survivorship, health and recruitment

3.2.1 Survivorship

Of the 24 hare-wallabies released on 29 and 30 August, only one is known to have died, four days post-release. This individual was a male rufous-hare-wallaby (RH02) from Bernier Island and the post-mortem found that this animal most probably died from capture myopathy. This animal was found dead at 0730 on 2 September and the carcass was retrieved within 30 minutes. The hare-wallaby was still soft and supple with no or little rigor mortis suggesting that death had probably occurred in the early morning. Photos of the hare-wallaby *in situ* were taken. There were no obvious signs of a predation event, but signs that the hare-wallaby had kicked with its front and rear legs while in the prone position. A field post-mortem was performed over the next few hours and samples taken for subsequent analysis by a veterinary pathologist (F. Coiacetto, Murdoch University). This analysis found that the cause of death was multifocal necrosis of the heart, mostly likely due to capture myopathy. It was noted that during processing and collar-fitting, this individual was hypersalivating, which is an indication of stress. However, the post-mortem also found that this animal had heavily worn and discoloured teeth, indicating this was an older animal and may have been more susceptible to capture myopathy.

In addition, ecto- and endo-parasites were examined by a veterinary parasitologist (A. Ash, Murdoch University). These analyses found ticks (*Amblyomma* sp.) on the body and helminthes (cestodes - *Progamotaenia* spp.; nematodes - *Labiostrongylus* spp., *Cloacina* spp.; pinworms - *Macropoxyuris* spp.) in the gut. However, it was noted that, although this individual harboured a large number of helminth parasites, this was not unusual for a macropodid. Under the scope of this analysis, most of the parasites found were not identified to species level. Most were likely to be previously described species found in other macropodids, but some may be undescribed.

All other hare-wallabies were known to be alive up to the time their radio-collars were removed. Table 2 shows the last time each animal was recorded alive. Eleven rufous and 10 banded hare-wallabies were successfully recaptured at the end of the intensive monitoring period. Of these, three rufous and two banded hare-wallabies had their collars removed due to rubbing, and two rufous hare-wallabies with GPS collars had these swapped for VHF only collars. Two banded hare-wallabies with GPS collars could not be recaptured, the batteries on these collars expired between the December and January aerial radio-tracking flights. Sixteen animals remained with VHF-only radio-collars at the end of the intensive monitoring period in late November 2017, and these were monitored by aerial radio-tracking in December, January, March and April at six-week intervals. By mid-May, all sixteen were still known-to-be-alive and fourteen were re-captured. Six banded and eight rufous hare-wallabies had their collars removed in May 2018, however two banded hare-wallabies could not be recaptured despite concerted efforts to do so.

Table 2. Individual translocated hare-wallabies and the date they were last known to be alive (individual recorded on remote camera after having collar removed; ** individual recorded on remote camera after collar battery died)*

ID	Species	Sex	Last recorded alive	Days elapsed	Method
RH02	*L. hirsutus*	M	2 September 2017	4	Deceased
RH03	*L. hirsutus*	M	20 March 2018	203	Remote camera*
DR04	*L. hirsutus*	M	8 May 2018	251	Recaptured (collar removed)
DR06	*L. hirsutus*	M	16 May 2018	259	Recaptured (collar removed)
DR01	*L. hirsutus*	F	8 November 2017	70	Recapture (collar removed)
RH01	*L. hirsutus*	F	14 November 2017	77	Remote camera*
DR02	*L. hirsutus*	F	13 April 2018	226	Remote camera*
DR07	*L. hirsutus*	F	10 May 2018	253	Recaptured (collar removed)
RH06	*L. hirsutus*	F	13 May 2018	257	Recaptured (collar removed)
RH04	*L. hirsutus*	F	14 May 2018	258	Recaptured (collar removed)
RH05	*L. hirsutus*	F	16 May 2018	260	Recaptured (collar removed)
DR05	*L. hirsutus*	F	17 May 2018	260	Recaptured (collar removed)
DB05	*L. fasciatus*	M	23 November 2017	85	Radio-tracked (not recaptured)
BH01	*L. fasciatus*	M	9 January 2018	133	Remote camera**
DB06	*L. fasciatus*	M	15 May 2018	258	Recaptured (collar removed)
BH03	*L. fasciatus*	M	16 May 2018	260	Radio-tracked (not recaptured)
BH04	*L. fasciatus*	F	10 November 2017	73	Recapture (collar removed)
BH05	*L. fasciatus*	F	30 January 2018	154	Remote camera*
DB01	*L. fasciatus*	F	8 May 2018	251	Recaptured (collar removed)
DB04	*L. fasciatus*	F	11 May 2018	254	Recaptured (collar removed)
BH06	*L. fasciatus*	F	12 May 2018	256	Recaptured (collar removed)
DB03	*L. fasciatus*	F	13 May 2018	256	Recaptured (collar removed)
DB02	*L. fasciatus*	F	14 May 2018	257	Recaptured (collar removed)
BH07	*L. fasciatus*	F	15 May 2018	259	Radio-tracked (not recaptured)

3.2.2 Health

The health of individual hare-wallabies was assessed at time of capture and recapture. Ectoparasites (mostly ticks) were observed and collected from one banded hare-wallaby and seven rufous hare-wallabies prior to release on Dirk Hartog Island but have yet to be identified. No ectoparasites were observed on subsequent recaptures of any animals, except for the individual (RH02) that died two days post-release.

During health-checks, weight was measured as an indicator of changes in condition. Hare-wallabies were weighed at time of capture on Bernier/Dorre Islands, at time of collaring and any time an individual was recaptured. Between initial capture and radio-collaring, all animals experienced weight loss, presumably due to stress caused by the capture and transfer to Dirk Hartog Island. During this time banded hare-wallabies lost approximately 4% (range: 2-9%) of their initial body weight (Figure 9). Rufous hare-wallabies lost an average of 13% (range: 8-18%) of their initial body weight in this initial 12-hour period. These weight losses were both statistically significant at the $p < 0.001$ level (t-test for matched pairs). However, when these rufous hare-wallabies were recaptured for collar checking/removal, weights had increased from time of collaring but few had reached their original capture weight (Figure 10). The rufous hare-wallaby that died four days after release (RH02) experienced the fourth highest weight loss (10.1%) over this period. However, the rufous hare-wallaby with the greatest initial weight loss of 18% was still alive and well on 8 May when its radio-collar was removed. Of the five banded hare-wallabies recaptured in May 2018, two had exceeded their initial capture weight, two were still below their capture weight and one weighed the same as its capture weight. Of the eight rufous hare-wallabies recaptured in May, two had exceeded their initial capture weight and six were still below their initial capture weight. Weights were not recorded for the remaining three animals. Quantitative condition scores for each animal were also estimated and predictably these mirrored the patterns that were observed for body weights. At capture, median condition index scores were 1.187 for banded hare-wallabies and 1.150 for rufous hare-wallabies. At collaring, these scores had dropped significantly ($p < 0.001$, t-test for matched pairs) to 1.171 and 1.094 respectively. At recapture these values had increased to 1.192 ($n = 10$) for banded (exceeding the original capture index) and 1.131 ($n = 11$) for rufous hare-wallabies. By May 2018, median indices for both species had stabilised with banded hare-wallabies at 1.183 ($n = 5$) and rufous hare-wallabies ($n = 6$) at 1.134, although the latter failed to attain their original condition scores.

During recapture in May 2018, animals were qualitatively assessed for condition and all but two scored three or above (ideal body condition). One individual was scored two and another 2.5 but these had large pouch-young or young-at-foot respectively.

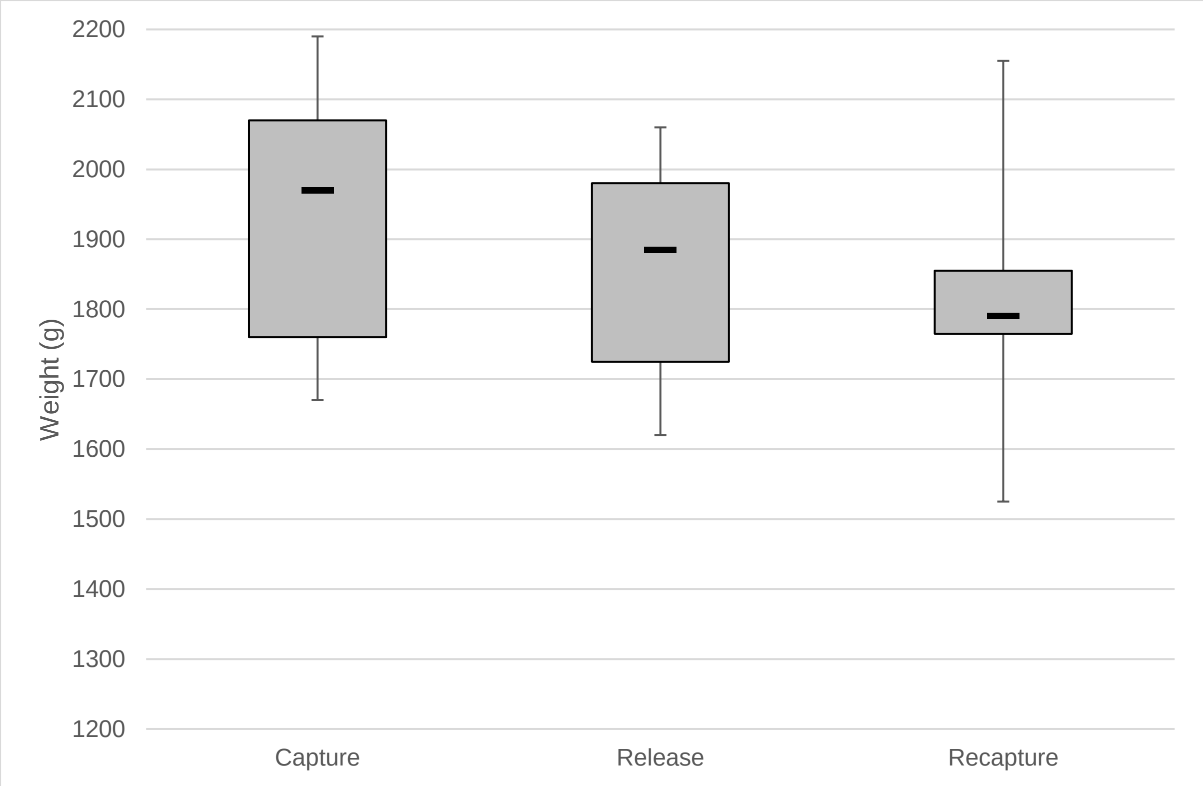

Figure 9. Box-whisker plot of weights of ***banded hare-wallabies*** *during intensive monitoring period. Black dashes show median weights, error bars are maximum and minimums (NB. Recapture weights do not include weight of collars).*

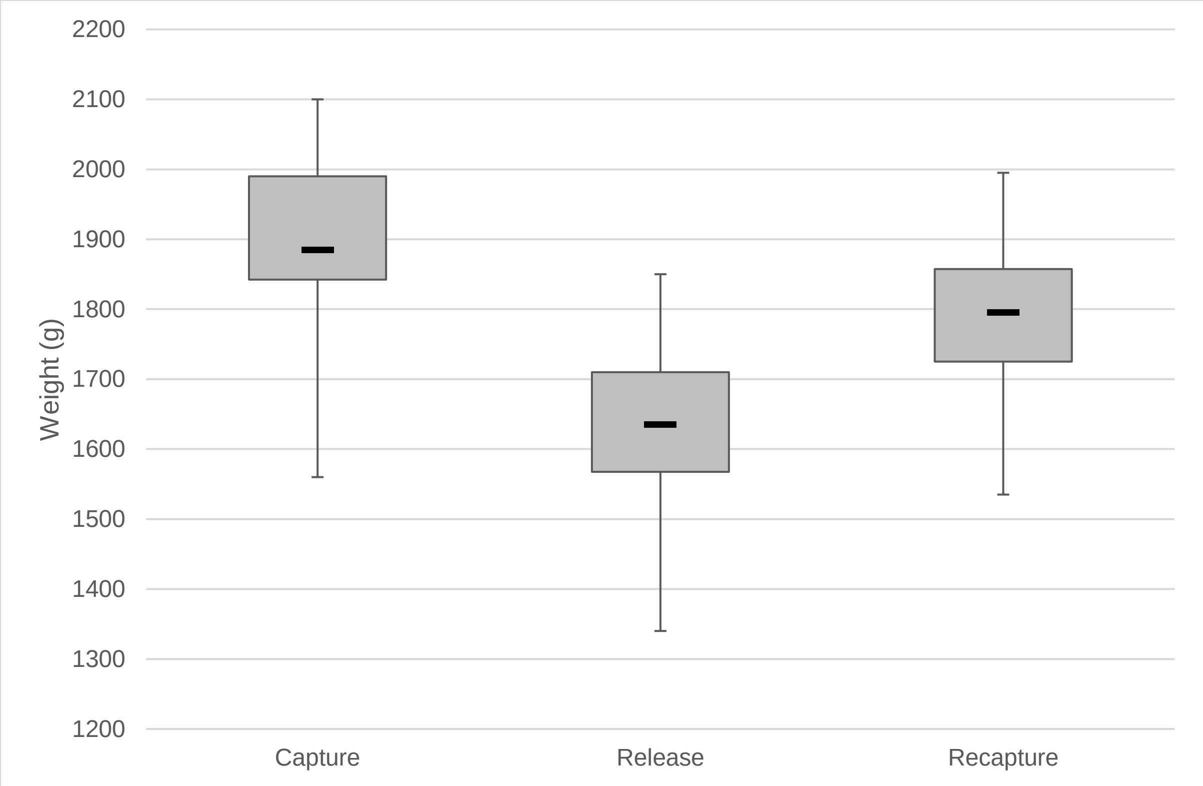

Figure 10. Box-whisker plot of weights of ***rufous hare-wallabies*** *during intensive monitoring period. Black dashes show median weights, error bars are maximum and minimums (NB. Recapture weight do not include weight of collars).*

3.2.3 Recruitment

Between October 2017 and May 2018, a total of six banded hare-wallaby and 10 rufous hare-wallaby pouch young or young at heel were recorded. Of these, four rufous hare-wallaby females produced joeys in spring and another in autumn. Table 3 summarises observations of reproductive activity in female hare-wallabies during the nine months post-translocation.

Table 3. Reproductive status of 16 female banded and rufous hare-wallabies during spring (September to November 2017) and autumn (May 2018) (collar removed in spring; ** not recaptured in autumn).*

ID	Species	Spring reproductive activity	Autumn reproductive activity
BH04	*Lagostrophus fasciatus*	PY 20mm	unknown*
BH05	*Lagostrophus fasciatus*	PY 30mm	unknown*
BH06	*Lagostrophus fasciatus*	regressing teat	PY; lightly furred
BH07	*Lagostrophus fasciatus*	regressing teat	unknown**
DB01	*Lagostrophus fasciatus*	regressing teat	empty, inactive
DB02	*Lagostrophus fasciatus*	PY 25mm	regressing teat
DB03	*Lagostrophus fasciatus*	regressing teat	PY; lightly furred
DB04	*Lagostrophus fasciatus*	possibly virginal	PY; lightly furred
RH01	*Lagorchestes hirsutus*	regressing teat	unknown*
RH04	*Lagorchestes hirsutus*	PY 40mm	PY; lightly furred
RH05	*Lagorchestes hirsutus*	regressing teat; pouch moist	PY 25mm & young-at-foot

RH06	*Lagorchestes hirsutus*	PY 40mm	regressing teat; pouch moist
DR01	*Lagorchestes hirsutus*	regressing teat	PY; fully furred
DR02	*Lagorchestes hirsutus*	PY 40mm	unknown*
DR05	*Lagorchestes hirsutus*	PY 25mm	PY 30mm
DR07	*Lagorchestes hirsutus*	PY 50mm	PY 20mm

3.3 Monitoring

3.3.1 Radio-tracking

Daily radio-tracking during the intensive monitoring period successfully obtained fixes for most animals every day during these 13 weeks. Two animals were detected in mortality mode: a male banded hare-wallaby whose collar malfunctioned and had latched in mortality mode after four hours but was still confirmed to be still alive; and the male rufous hare-wallaby who was found deceased (see section 3.2.2).

While radio-tracking to establish status and approximate location was relatively straightforward, triangulations to obtain more accurate locations were more challenging. The VHF collars in particular were often difficult to achieve accurate bearings as some signals were only able to be picked up with the antenna in a vertical orientation, which does not provide as much directional discrimination as the horizontal orientation. This, combined with a range of different radio-tracking experience levels among staff and volunteers and undulating terrain, made for a high probability of error in bearings taken for the strongest signal. Consequently, data obtained from triangulations was generally poor with broad confidence intervals. However, these data do provide an insight into the movements of translocated hare-wallabies (Figure 11). Generally, banded hare-wallabies were located in refuges to the east of the release area, where habitat was dominated by *Acacia* sp. communities, while rufous hare-wallabies were generally located in refuges in the centre of the release area, where *Triodia plurinervata* is the dominant species. However, there was some variation and overlap between habitat types used by the two species, mainly on an individual basis.

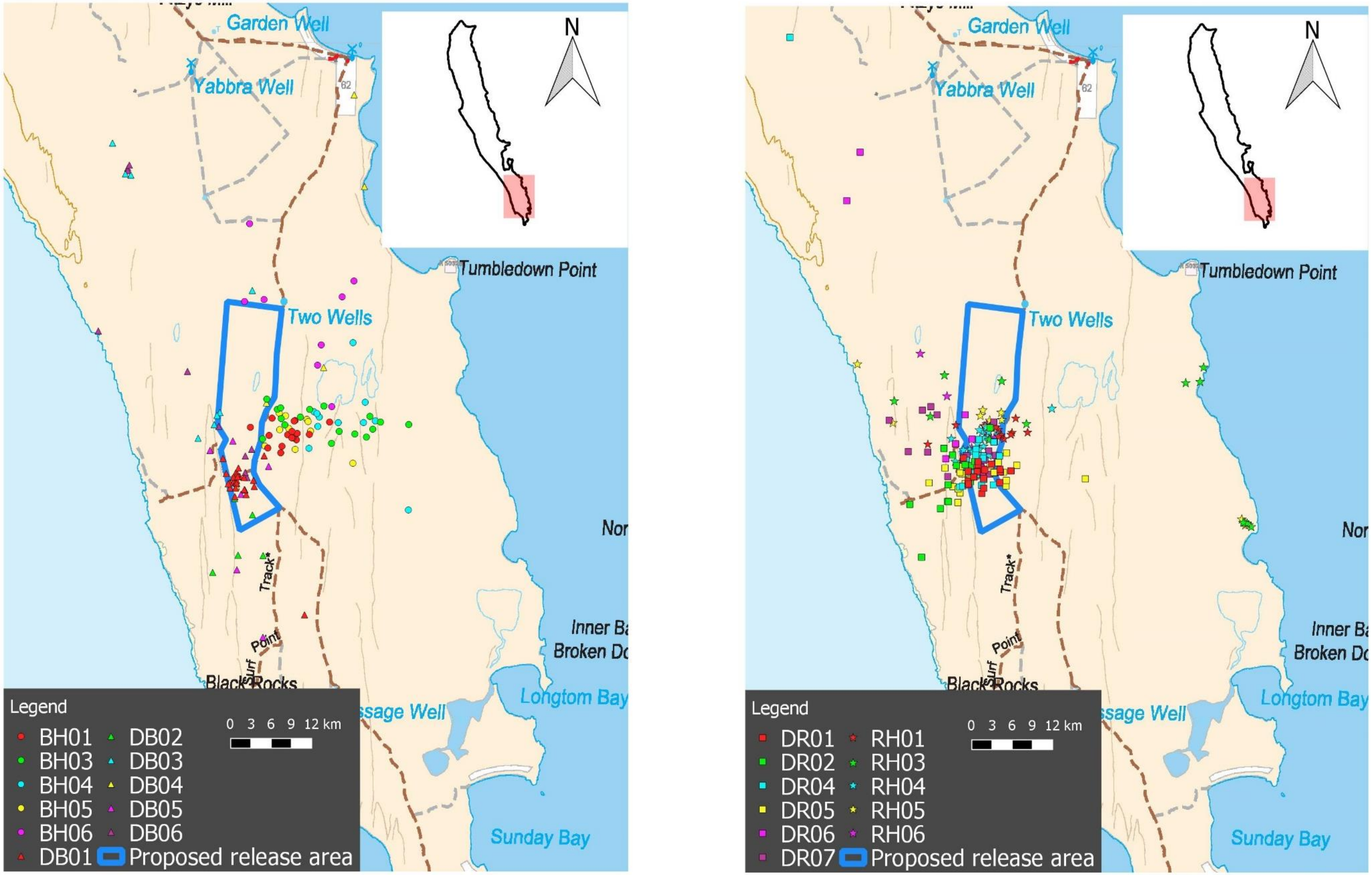

Figure 11. Map of locations for banded (left) and rufous hare-wallabies (right) from triangulations obtained by radio-telemetry.

GPS collar data tended to be to be more reliable since data points were not subject to human error. However, GPS fixes are also prone to some errors depending on the collars themselves and the surrounding environment (Adams *et al*. 2013). Between 24% and 57% of GPS fixes from the six collars deployed were below the thresholds outlined in 2.3.1 and were removed from the movement analyses (Table 4). In addition, due to problems with obtaining remote downloads from two of these collars (both fitted to banded hare-wallabies that were not recaptured), only nine and 15 days' worth of data were available for analysis. However, despite the low number of data-points, GPS fixes for the six collars were used to produce 95% minimum convex polygon (MCP95), and 95% Kernel Density Estimates (KDE95) to estimate utilisation distributions (UD) (Figure 12). It should be noted that the KDE polygon for RH05 actually incorporated an area of ocean, reflecting the level of accuracy in these estimates of UD. It is clear that there were large differences in the movements of some animals, for example rufous hare-wallaby DR01 moved over approximately 33 ha, while another rufous hare-wallaby RH05 moved over 1099 ha.

Table 4. Data obtained from GPS collars, including estimations of utilisation distribution (UD) for six hare-wallabies (NB. Low numbers of points for BH05 and DB05).

Capture ID	Species	Sex	Total no. points	Period (days)	Mean points per day	MCP95 (ha)	KDE95 (ha)
BH01	BHW	M	249	50	4.98	17	37
BH05	BHW	F	77	15	4.8	13	30
DB05	BHW	M	42	10	4.2	26	350
RH05	RHW	F	300	69	4.35	1099	2126
DR01	RHW	F	492	70	7.03	33	23
DR02	RHW	F	274	34	8.15	36	147

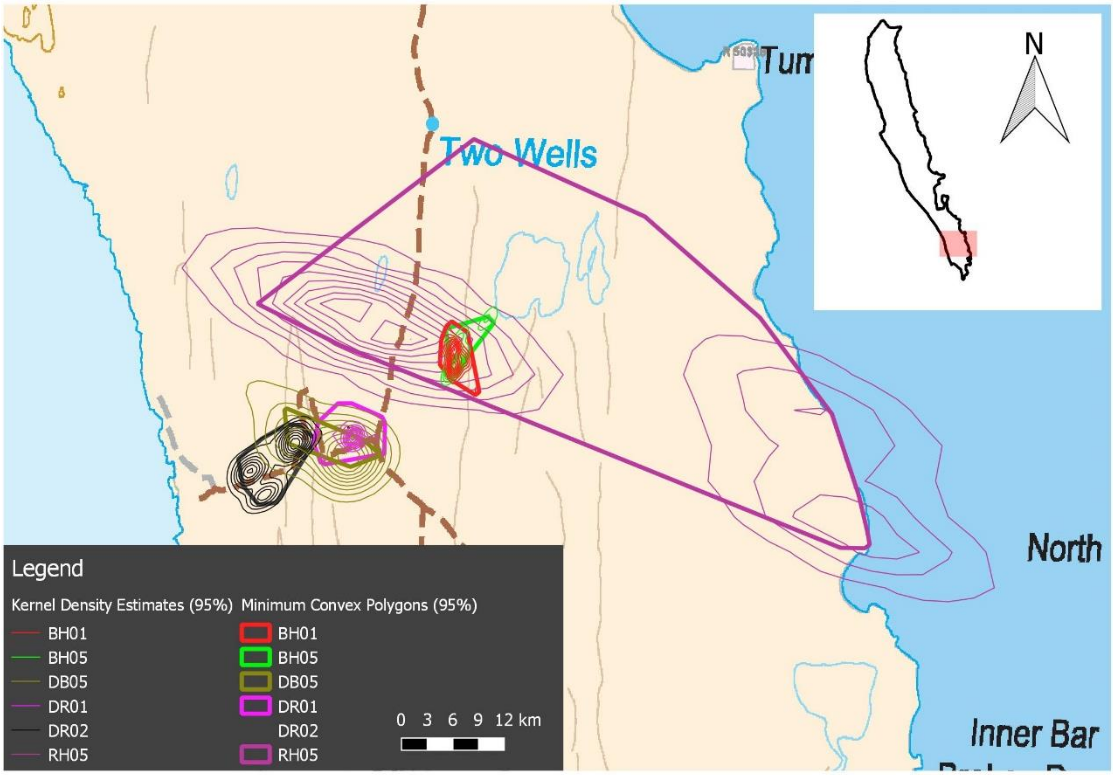

Figure 12. Map of utilisation distributions (95% MCP and KDE polygons) for six hare-wallabies fitted with GPS collars.

In addition to using the GPS fixes to estimate UD, these data were also used to estimate daily movements. Due to the way in which the collars were programmed, the only days that could produce reliable data for these were those with the highest number of fixes per day: 19 and 20 September 2017. Although 21 fixes per day were scheduled for these days, the actual number of fixes varied between 11 and 21. Movements per day varied between 296m and 1,291m for rufous hare-wallabies with an average of 831m over the two days. Only one banded hare-wallaby out of three had fix data for these dates (BH01) and moved 1,008 on the 19 September and 1,166m on the 20 September. Overall (i.e. for all fix data) the largest daily movement for banded hare-wallabies was 2,813m (DB05) and for rufous hare-wallabies 4,475m (RH05), the latter also having by far the largest UD (Figure 12).

Radio-tracking effort after the initial intensive monitoring period had ceased was reduced to six-weekly aerial radio-tracking flights over the island. This proved a very efficient method of locating animals and triangulating their positions. Four tracking flights took place and the results of these flights are shown in Figure 13. Generally, movements of hare-wallabies by this time had stabilised and most animals were recorded in similar locations on all four occasions. Ground radio-tracking in May 2018 found that day refuges were often very close (<100m) to locations obtained previously from the air.

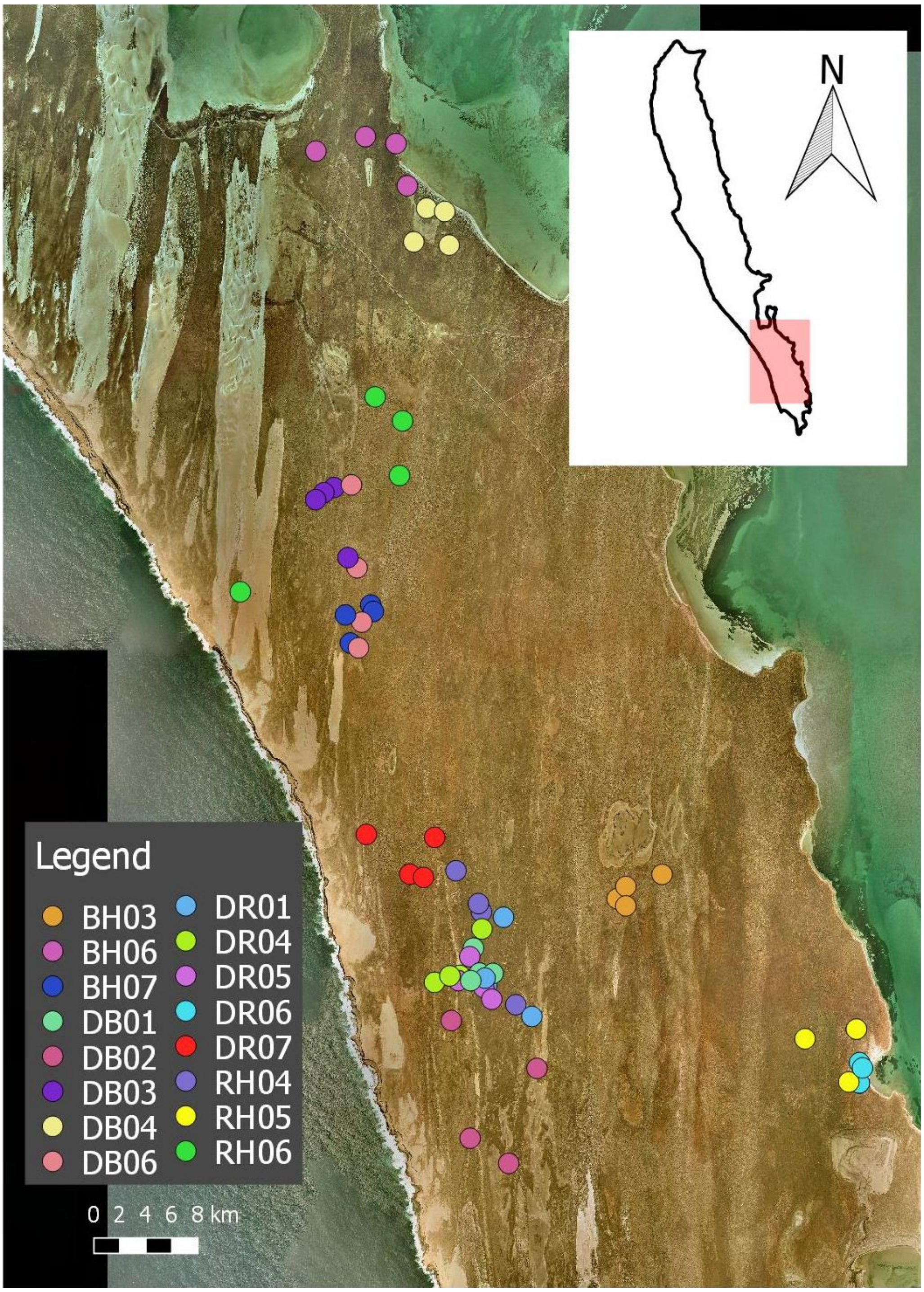

Figure 13. Map of VHF collared hare-wallaby locations obtained from aerial radio-tracking efforts in December, January, March and April 2018.

3.3.2 Remote cameras

Between November 2017 and May 2018, only four of the 30 remote cameras on the main grid recorded hare-wallabies; three cameras recorded rufous hare-wallabies and one recorded banded hare-wallabies. (Figure 14). . One camera recorded rufous hare-wallabies on 23 nights and another recorded banded hare-wallabies on four nights while the remaining two cameras recorded rufous hare-wallabies on single nights only. Since there were so few records of hare-wallabies on the monitoring grid, we were unable to use these data to estimate Ψ or occupancy. However, the cat detection camera network across DHI maintained by the cat eradication team was successful with 14 cameras recording rufous hare-wallabies on 38 nights in total, although only three cameras recorded banded hare-wallabies. Two cameras of these cameras recorded rufous hare-wallabies on 14 and 11 nights. This included a male rufous hare-wallaby (DR06) that could not be located for several weeks. This individual was located on cat monitoring cameras in the northern boundary of the southern sector of the island, captured on a camera at the cat-proof fence, approximately 35km from the release area (Figure 14). These data proved invaluable and this individual was eventually located and captured using the information provided by these cameras. Another example of the value of the cat camera array was the discovery of an unknown rufous hare-wallaby in an area where only banded hare-wallabies had been recorded. This was likely to be the offspring of a female living 2.5km away who had a pouch young in November 2017 that would have been weaned by April 2018 when the new animal was recorded.

Targeted monitoring of individuals that had had their collars removed was also somewhat successful, with animals being located again after the collar removal (Figure 14; Table 2). However, on two of the three grids set out to target these particular individuals, only one camera recorded hare-wallabies.

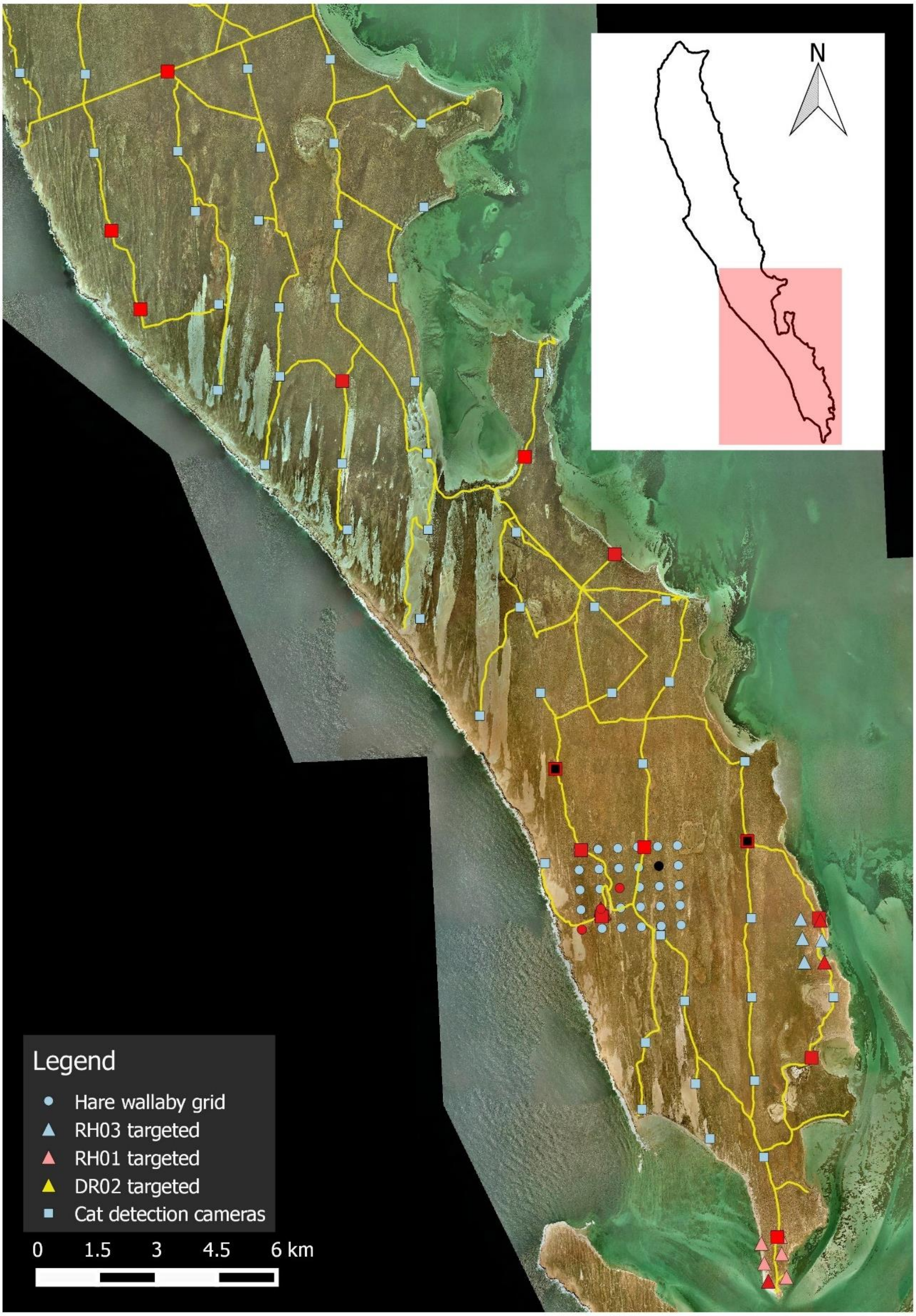

Figure 14. Map of remote camera locations and observations of hare-wallabies (red symbols – rufous hare-wallabies; black symbols – banded hare-wallabies).

3.3.3 Tracks and scats

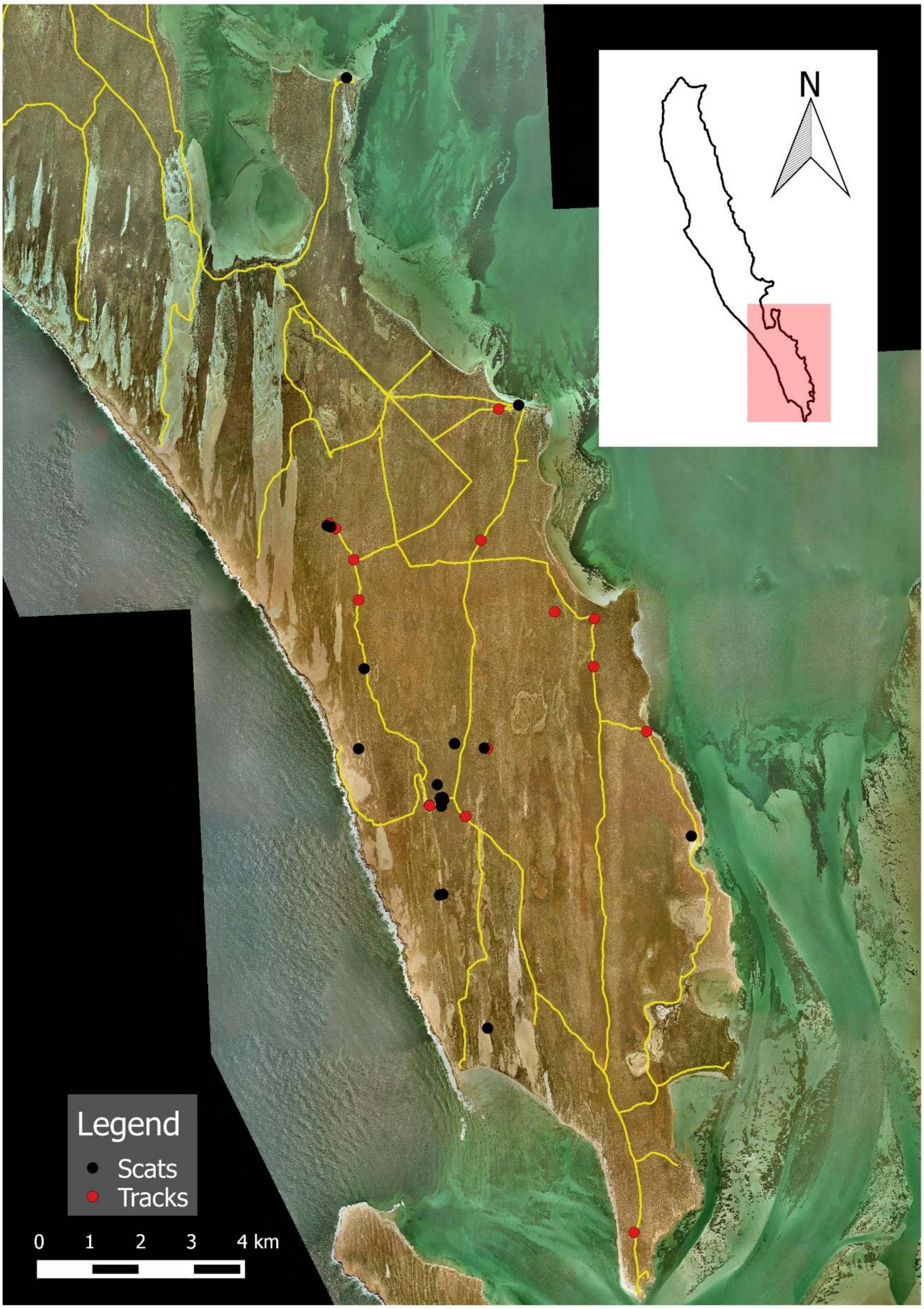

Figure 15. Map of locations where tracks or scats were observed during post-release intensive monitoring period.

Hare-wallaby scats and tracks were observed widely across the southern section of DHI, from Cape Ransonnet in the south, to Notch Point in the north (Figure 15)

Preliminary analysis of scats from three banded and three rufous hare-wallabies found seeds from several different species of plants (A. Cochrane *pers. comm.*) including probable *Eremophila* sp. and *Ptilotus* sp. (both from rufous). Other species remain unidentified and a reference collection of seeds is likely to be required to complete the identification process.

4 Discussion

4.1 Translocation outcomes

The 2017 translocation of rufous and banded hare-wallabies to Dirk Hartog Island was a trial to assess translocation procedures and determine where protocols could be improved. It also provided the opportunity to test the suitability of DHI for banded and rufous hare-wallabies and how to improve the likelihood of a successful outcome in the future, larger-scale translocations. Meeting the short-term translocation success criteria gives confidence that translocations with larger founder numbers will also be successful.

All short-term success criteria (one to four) were met by this trial and three (one to three) out of four medium-term criteria were also met. Survivorship was almost certainly 100% for banded hare-wallabies and likely to be 92% for rufous hare-wallabies (one mortality out of 12). The only hare-wallaby that died during this trial translocation was examined by a veterinary specialist and the conclusion was that capture myopathy was the likely cause of death. This animal displayed other symptoms of stress (e.g. hypersalivation; weight loss) but so did several other animals which survived and apparently thrived. However, this individual was found to have heavily worn teeth, suggesting it was an older animal and potentially more susceptible to capture myopathy. Capture myopathy is a known issue with not just rufous hare-wallabies but macropodids in general. This incidence suggests that the protocol for translocation can be improved (see Recommendations).

No mortalities or incidents as a result of predator interactions were recorded despite birds of prey, including wedge-tailed eagles, being sighted over the release area on a semi-regular basis. This outcome my have been due in part to vigilance for the presence birds of prey and a concerted effort not to disturb hare-wallabies during the day. While we expect that the increase of mammal abundance during the course of the translocation program (hence increasing prey availability) will eventually result in predation events, continued efforts not to draw attention to animals will be necessary to help ensure the successful establishment of hare-wallabies on DHI.

After an initially large weight loss between capture and release on DHI, all rufous hare-wallabies have gained weight with three now weighing more than when initially captured. All banded hare-wallabies also lost weight between capture and collaring on DHI, however these losses were not as substantial as those sustained by rufous hare-wallabies. Four banded hare-wallabies recaptured since release have lost further weight (between 10-220g), but all remaining animals have put on weight and in May 2018, all but one had surpassed initial capture weight. However, most of these were females with pouch young or young-at-foot, which may have contributed towards their loss of weight. Most animals assessed in May were of average or above average condition so there were no concerns over their ability to find adequate food. An important lesson from this translocation was that hare-wallabies (particularly rufous) may lose a substantial amount of weight when subjected to significant stress, but this weight loss is not necessarily indicative of their likelihood of survival.

No females were translocated with young, but pouch-young were recorded early on in the trial (first on 3 October, just over a month post-release) and in total 16 pouch young or young-at-foot were recorded (10 rufous; six banded) and the total may have been more. While some of the spring records may have resulted from embryonic diapause, pouch-young recorded in autumn would all have been conceived on Dirk Hartog Island. Therefore, we are confident that this translocation has been successful to date and the program can look to proceed with further translocations of both these species in 2018 and 2019.

The potential level of recruitment into the new population was encouraging and assuming all the pouch young observed in spring and autumn were recruited into the population, this would mean the rufous hare-wallaby population has increased by almost 100% in 12 months, and the banded hare-wallaby population by 50%. This indicates that these cohorts have adjusted well to their new environment and are finding adequate food and shelter resources.

4.2 Monitoring outcomes

Monitoring by radio-tracking proved to be an effective method of establishing the status of individual hare-wallabies on a daily basis. Most animals were located every day which meant any mortalities could be (and were) followed up on rapidly for immediate post-mortem assessment to establish probable cause of death. Furthermore, it helped develop a better understanding of the variation in post-translocation movement of hare-wallabies around the landscape, with some animals remaining close to their release area, while others travelled large distances before settling down in discrete locations. It also reinforced our previous knowledge of the habitat preferences of each species, with the individuals that established home ranges outside the selected release area still settling in areas dominated by habitats that we had initially selected for each species i.e. *Acacia* shrubland for banded hare-wallabies and *Triodia* grassland for rufous hare-wallabies.

Triangulating accurate locations of hare-wallaby refuges was problematic, with levels of accuracy fluctuating widely. However, the importance of achieving highly accurate locations is less than establishing a) establishing if the animal was alive, b) if the animal has moved a significant distance and c) what vegetation community the animal is choosing to refuge in. The data collected from the radio-tracking effort in this trial were sufficient to address these questions. Nevertheless, the time and effort required to obtain triangulations for all animals on a regular basis may not be justified if similar answers can be attained from obtaining just one or two fixes on each collar per day. In future, the value of obtaining accurate triangulations may be more for locating individuals that have moved a large distance from their previous known refuge, so that it may be located more easily in the future.

GPS collars provided relatively high-resolution movement data, which provided useful information in how a handful (six) hare-wallabies were behaving and using the landscape. However, due to the inaccuracy of many of the GPS fixes, combined with the malfunction of the remote download facility on two of the collars, these data were ultimately of limited utility. Nevertheless, the insights that these GPS data provide are tantalising and highlight the potential value that this technology can have in understanding how translocated hare-wallabies acclimatise and prosper in a new environment. Another issue with the GPS collars was the range at which a remote download could be obtained using the provided base-station. The manufacturer claimed that 100-200m was possible, but in trials the best we could achieve was 50m in light-of-sight. This was problematic, as getting this close to a hare-wallaby entails the risk of flushing and consequently potential predation by raptors if during daylight hours. This is an important consideration for monitoring future hare-wallaby translocations.

Monitoring using cameras had mixed results, with the 2500 x 2000m camera grid (at 500m spacings) established near the release area recording very few observations of hare-wallabies of either species. In contrast, the track-based camera grid used by the cat eradication team proved very useful for non-systematic monitoring of hare-wallaby movements and assisted with relocating individuals that had moved substantial distance. Since we were unable to use either of these grids to estimate Ψ and occupancy, it highlights the need to review and revise our methodology in order to obtain a greater number of observations on remote cameras. It may be that camera arrays are not an optimal strategy for monitoring hare-wallabies, but more work is needed in this area before it is ruled out. Certainly, cameras may hold considerable value for monitoring other species but it may be that the methodology needs to be improved to incorporate hare-wallabies.

Scat collection was maintained throughout and after the intensive monitoring period and the samples will hopefully be used for diet analysis, with some preliminary work on dietary preferences and endozoochory already underway. Establishment of a reference seed collection for both Bernier and Dorre and Dirk Hartog Islands will commence in 2018. However, the protocol for storage of scats needs to be revised with about six percent of samples becoming mouldy, despite being stored on silica gel. It may be more appropriate to dry some scat samples prior to storage, whilst ensuring that this does not compromise the samples for other applications (e.g. DNA extraction and analysis).

4.3 Recommendations

Based on the results of this trial and with a view to further improving translocation and monitoring protocols for future translocations of rufous and banded hare-wallabies, we make the following recommendations

1. This trial translocation met all its short-term success criteria (and 75% of its medium-term success criteria) indicating that Dirk Hartog Island is most likely suitable habitat for these two hare-wallaby species, and that a large-scale translocation (40-50 animals) of both these species should be successful.

2. Time spent transporting animals between Bernier/Dorre Islands and Dirk Hartog Island would be greatly reduced through the use of a helicopter. Helicopter transfers between islands would take 20-30 mins, compared to the ~5 hrs taken by the vessel used in the 2017 translocation. It is hoped that less time spent in transport (method not being subject to potentially rough conditions) will reduce stress levels and reduce the likelihood of mortality from capture myopathy. This may also ameliorate the large weight losses observed for the rufous hare-wallabies in particular.

3. The significant weight loss (up to 18% of body weight) by some individuals in <24 hours during the translocation, was undoubtedly predominantly fluid loss, as a result of urination and hypersalivation during the transportation and holding prior to release. This level of fluid loss is likely to have resulted in significant dehydration, potentially compromising survival for these animals, and it may be beneficial to provide some fluid replacement for extreme cases in future translocations. However, the potential benefit would need to be weighed carefully on a case-by-case basis, against the additional stress and discomfort involved in such additional intervention.

4. Daytime radio-tracking during future translocations should focus on determining a) collar status and b) approximate location and vegetation community that the animal is taking refuge in. Approaching refuges will continue to be restricted to night-time only in an effort to prolong naivety of birds of prey to the presence of the hare-wallabies. Triangulations, while a useful technique to obtain accurate location data, are time-consuming and vary widely in levels of accuracy. Therefore, triangulated positions should mostly be obtained for individuals that move large distances. Staff should ensure that all personnel (including volunteers) should be given adequate training in obtaining triangulated positions and results should be tested for accuracy using e.g. the Triangulation plugin in Quantum GIS.

5. GPS telemetry collars should continue to be used as an important source of information on landscape use by translocated hare-wallabies. However, future purchases of collars should be capable of obtaining downloads from at least 150m away, rather than the 50m that the units used in 2017 were able to achieve. Also, the GPS schedule should be consistent so that more accurate estimates of movement and utilisation distribution can be obtained.

6. The 2500 x 2000m (500m-spacing) camera grid was not successful as a monitoring program for the translocated hare-wallabies. Only 13.3% of cameras recorded any hare-wallabies over six months. However, for species like banded and rufous hare-wallabies, passive monitoring techniques such as remote cameras are still worthy of consideration. It is recommended that a revised technique is trialled in 2018, potentially with a larger number of cameras being deployed.

7. Fresh scat samples should be dried prior to storage on silica gel. The potential of scat-plots as a future (multi-species) monitoring tool should be investigated, to assist with a feasibility study on obtaining population estimates from DNA extracted from scats. A reference library of seeds should be collected to assist with identification of plant species consumed by hare-wallabies.

8. Although no interactions with or predations by large raptors were recorded during this trial translocation, as the populations of banded and rufous hare-wallabies increase through translocations and reproduction, inevitably the probability of these events occurring will also rise. Furthermore, large raptors may change their behaviour to spend more time in areas where hare-wallabies are present. Monitoring of the presence of wedge-tailed eagles and white-bellied sea-eagles (*Haliaeetus leucogaster*) should be undertaken, with the aim of identifying any changes in abundance or behaviour in the future.

9. As numbers of hare-wallabies on DHI increase, the risk of interactions with vehicles will also increase, particularly if travelling at high speed. Signs warning members of the public to slow down for wildlife, particularly between dusk and dawn, are planned to be positioned strategically around the island to help mitigate this risk to hare-wallabies and other native fauna.

Appendices

Appendix 1 Capture information of hare-wallabies translocated to Dirk Hartog Island August 2017

Capture ID	Capture Date	Capture Location	Species	Sex	Age	Collar Type	Capture Weight (g)	Head Length (mm)	Long Pes (mm)
BH01	28/08/2017	Bernier Island	*Lagostrophus fasciatus*	M	A	GPS	2190	83.5	102.5
BH03	28/08/2017	Bernier Island	*Lagostrophus fasciatus*	M	A	VHF	1690	84.2	105.9
BH04	28/08/2017	Bernier Island	*Lagostrophus fasciatus*	F	A	VHF	1750	85.2	102
BH05	28/08/2017	Bernier Island	*Lagostrophus fasciatus*	F	A	GPS	1790	86.4	100.5
BH06	28/08/2017	Bernier Island	*Lagostrophus fasciatus*	F	A	VHF	2040	86.4	103.2
BH07	28/08/2017	Bernier Island	*Lagostrophus fasciatus*	F	A	VHF	1670	82	104
RH01	28/08/2017	Bernier Island	*Lagorchestes hirsutus*	F	A	VHF	1730	86.2	106
RH02	28/08/2017	Bernier Island	*Lagorchestes hirsutus*	M	A	VHF	1990	82	105.5
RH03	28/08/2017	Bernier Island	*Lagorchestes hirsutus*	M	A	VHF	1870	82.6	107.6
RH04	28/08/2017	Bernier Island	*Lagorchestes hirsutus*	F	A	VHF	2080	79.8	109.7
RH05	28/08/2017	Bernier Island	*Lagorchestes hirsutus*	F	A	GPS	1940	81.8	106.6
RH06	28/08/2017	Bernier Island	*Lagorchestes hirsutus*	F	A	VHF	1840	78.3	107.7
DB01	29/08/2017	Dorre Island	*Lagostrophus fasciatus*	F	A	VHF	2110	81.1	99.8
DB02	29/08/2017	Dorre Island	*Lagostrophus fasciatus*	F	A	VHF	2070	80.8	104.4
DB03	29/08/2017	Dorre Island	*Lagostrophus fasciatus*	F	A	VHF	1910	83.9	107.2
DB04	29/08/2017	Dorre Island	*Lagostrophus fasciatus*	F	A	VHF	1690	81.5	103.3
DB05	29/08/2017	Dorre Island	*Lagostrophus fasciatus*	M	A	GPS	2030	83.1	106.2
DB06	29/08/2017	Dorre Island	*Lagostrophus fasciatus*	M	A	VHF	2190	82.6	112
DR01	29/08/2017	Dorre Island	*Lagorchestes hirsutus*	F	A	GPS	1710	82.2	107.8
DR02	29/08/2017	Dorre Island	*Lagorchestes hirsutus*	F	A	GPS	2020	83.9	111.3
DR04	29/08/2017	Dorre Island	*Lagorchestes hirsutus*	M	A	VHF	1850	79.5	106.2
DR05	29/08/2017	Dorre Island	*Lagorchestes hirsutus*	F	A	VHF	1560	78.9	107.2
DR06	29/08/2017	Dorre Island	*Lagorchestes hirsutus*	M	A	VHF	2100	83.5	110.2
DR07	29/08/2017	Dorre Island	*Lagorchestes hirsutus*	F	A	VHF	1900	81.9	106.1

Appendix 2 List of species recorded on remote cameras (November 2017 to May 2018)

Common Name	Scientific Name	% grid points
Australian pipit	*Anthus australis*	3.33
Banded hare-wallaby	*Lagostrophus fasciatus*	3.33
Black-faced woodswallow	*Artamus cinereus*	3.33
Grey butcherbird	*Cracticus torquatus*	10.00
Little crow	*Corvus bennetti*	40.00
Little long-tailed dunnart	*Sminthopsis dolichura*	10.00
Unknown rodent		36.67
Rufous fieldwren	*Calamanthus campestris*	46.67
Rufous hare-wallaby	*Lagorchestes hirsutus*	10.00
Sand goanna	*Varanus gouldii*	63.33
Singing honeyeater	*Gavicalis virescens*	6.67
Spotted military dragon	*Ctenophorus maculatus*	3.33
Spotted nightjar	*Eurostopodus argus*	3.33
Stubble quail	*Coturnix pectoralis*	3.33
White-winged fairy-wren	*Malurus leucopterus*	3.33

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